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PROGRAM MANAGEMENT COURSE
INDIVIDUAL STUDY PROGRAM

ACQUISITION MANAGEMENT THROUGH
DIGITAL INTEGRATION

STUDY PROJECT REPORT
PMC 76-2

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DEFENSE SYSTEMS MANAGEMENT COLLEGE

STUDY TITLE: ACQUISITION MANAGEMENT THROUGH DIGITAL INTEGRATION

STUDY PROJECT GOALS:
To define and evaluate management issues that result from the introduction of digital technology into tactical guided weapons.

STUDY REPORT ABSTRACT:
The purpose of this study project was to understand the impact of digital technology on the management of tactical guided weapons and to formulate management considerations for future procurements by investigating the GBU-15 program and developmental concepts. This was accomplished by an expansion of the writer's personal knowledge and background in the area through data collection from Government and Industrial sources and through interviews at Hq USAF, Hq AFSC, and the Armament Development and Test Center (ADTC).

Digital integration was found to have distinct advantages over traditional analog concepts in terms of cost, operational flexibility and growth potential. However, the introduction of digital technology into a system impacts a number of acquisition management parameters. These include procurement, life cycle costs, the logistics/maintenance philosophy, and software management. Special attention is required in each of these areas during system development due to the use of software change as the integrating function. The digital integration concept applies to other types of systems such as aerial targets, aircraft avionics, and remotely piloted vehicles.

The study conclusions are that system integration through digital processing is the key to cost effective development and deployment of DOD weapon systems. A significant learning process must take place within the Defense establishment to facilitate employment of this new management concept. Procurement procedures should be established to insure effective competition among contracters for digitally integrated systems. Digital integration has the potential for tri-Service application.

The conclusions outlined in this report should serve as a baseline for the effective management of future programs involving digital technology. The special areas of emphasis discussed will allow program managers to consider early in their efforts the impact of digital integration on management procedures.

SUBJECT DESCRIPTORS: Guided Weapons, Digital Integration.

NAME, RANK, SERVICE	CLASS	DATE
Lawrence F. Sokolowski, MAJ, USAF	PMC 76-2	November, 1976

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ACQUISITION MANAGEMENT THROUGH DIGITAL INTEGRATION

Study Project Report

Individual Study Program

Defense Systems Management College

Program Management Course

Class 76-2

by

Lawrence Francis Sokolowski
Major USAF

November 1976

Study Project Advisor
Mr. William M. Cullin

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EXECUTIVE SUMMARY

In an effort to reduce cost and increase operational flexibility the Air Force has studied the concept of modular weapons for the past six years. The application of this concept to tactical guided weapons has proven to be far more difficult than anticipated due primarily to the use of analog hardware. The relative inflexibility of analog integration, coupled with the extreme cost of integrating new capabilities, both in the weapon and in the aircraft, have made the digital approach attractive.

The availability and cost effectiveness of digital technology led to the development of the programmable digital autopilot (PDAP) and the digital processor (DP). With the successful development and demonstration of the PDAP, the concept of system integration through digital processing is being achieved in the GBU-15 Modular Guided Weapon System. Software change as opposed to costly hardware modification is being used to integrate the modular components of that system.

The development and demonstration of the DP will allow the total integration of future weapon systems by performing the entire range of computational functions associated with a guided weapon.

The introduction of digital integration into the guided weapon development process has had a profound effect on management considerations. Specifically when digital technology is applied the program manager must access the impact on procurement, life cycle costs, the logistics/maintenance philosophy and software management. Each of these areas requires attention due to the use of software change as the integrating function. In addition, digital processors for guided weapons are considered a technology that has broad

application within the DOD. An effort to control proliferation of such devices was initiated by DDR&E and their involvement has resulted in an approved tri-Service plan.

Although the study is confined to the use of digital integration in guided weapons, the concept has application to a wide range of major defense systems. In each case the success of the concept depends on the special management provisions uniquely attributable to digital software.

The conclusions drawn from this study are that system integration through digital processing is the key to cost effective development and deployment of DOD weapon systems. A significant learning process must take place within the Defense establishment to facilitate the employment of digital technology as the integrator in future programs. Procurement procedures must be established to insure effective competition of digitally integrated systems. This can be accomplished in part by Service control of the interfaces between modules through flexible digital system specifications. Digital integration will allow cooperation among the Services in exploiting the benefits of this new and promising management concept.

The conclusions and recommendations derived during the course of this study are based in part on the author's personal experience in the areas of acquisition management and deployment of conventional weapons. Included are operational tours of duty in Europe and Southeast Asia and in Research and Development as Program Manager of the Digital Guided Weapons Technology (DGWT) program. During the latter assignment, the PDAP was developed, evaluated, and transitioned into engineering development as part of the GBU-15 program. Initial work was also accomplished on the fabrication and evaluation of the DP for future weapon systems.

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SECTION I

INTRODUCTION

For the past several decades, air-to-surface weapons have formed a significant element of this nation's tactical arsenal. World War II proved the importance of aerial bombing in attacking various types of targets. It became clear that fundamentally different weapons were required for destroying bridges, buildings, bunkers, transportation systems, and troop concentrations; thus an assortment of bombs with little component interchangeability were designed to satisfy critical requirements. Delivery accuracy of these unguided weapons relied on the skill and training of pilots and bombardiers. Once the bombs left the aircraft, they followed ballistic trajectories and were subject to dispersion from a number of sources such as wind and drag characteristics. In order to assure that a given target would be destroyed, it was often necessary to fly numerous sorties and to expend large quantities of munitions. Aircraft crews were exposed repeatedly to enemy defenses, and non-targeted facilities were unnecessarily destroyed in the process.

Developments in electronic technology since World War II provided a new capability which has revolutionized the delivery of air-to-surface weapons. That capability is homing guidance. If the guided weapon can sense its target's location and steer to that target, impact accuracy can be markedly improved, reducing the required number of sorties to achieve a specific objective, minimizing the size and number of warheads required to destroy the target, and diminishing the possibility of striking non-targeted facilities. Accordingly, there have been highly successful applications of homing guidance to air-to-surface weapons in recent years which have increased strike force

efficiency and have made "surgical" attack a reality.

While technology has been deomonstrated and, in fact, has become operational, it has been achieved with dedicated hardware. Each weapon system has been developed as an entity, and there is little interchangeability of the costly electronic components and control mechanisms which are required for homing guidance. Furthermore, continuing advances in digital technology have yet to be fully incorporated into air-to-surface weapons. The proper utilization of this new technology shows promise as an approach for achieving weapon system integration through digital processing. This study was undertaken to understand and evaluate the impact of digital integration on acquisition management.

General Considerations

Air Force Magazine stated in the April 1975 issue that:

> "Among the potentially far-reaching programs in progress at the Air Force's laboratories--traditionally catalysts of major new weapons technology--are modular guided weapons, an Air Force pioneered technology that 'is really coming into its own,' according to Air Force Systems Command's (AFSC's) Director of Science and Technology Brigadier General G. K. Hendricks. Aimed at versatile, flexible standoff capabilities, AFSC's modular guided weapons concept provides for a quick interchange of the principle components of guided standoff weapons, permitting field commanders to tailor them to specific missions.
>
> "A common, crucial element of standoff weapons is a compact, economical guidance package to provide midcourse or terminal guidance and a reliable autopilot. In the case of the latter, General Hendricks said, 'It will first be necessary to use different autopilots to accommodate different combinations of modules. But work at the Armament Laboratory at Eglin AFB, Florida, and elsewhere on digital autopilots has proved the feasibility of a programmable system that could be used by the entire family of proposed standoff weapons.'"

This emphasis on digital integration to significantly improve the management of the weapons acquisition process resulted primarily from two factors.

First, the rapid expansion of the digital technology base within the

past few years resulted in a new class of digital computers called microprocessors or microcomputers. This new technology is now developing into a cost-effective solution for mechanizing many computational requirements including autopilots. This technology is particularly applicable to guided weapons because of its physical size, performance, cost, and the inherent ease with which the autopilot, guidance equations, and control sequence can be adopted to a variety of configurations through system programming.

Second, the soaring costs associated with utilizing analog hard-wired components has made the integration process between weapon subsystems and between the weapon system and aircraft nearly prohibitive. One needs only to look at aircraft modification costs to be convinced that new and innovative techniques must be developed to maintain a strong and cost-effective weapons posture. Digital processing, which will allow weapon integration and aircraft interface through software change appears to be a viable solution to the management and control of weapon systems development.

Purpose and Scope

The purpose of this study is to provide the writer with an understanding of (1) impact of digital technology on the management of tactical guided weapons, and (2) to formulate management considerations for future procurements by investigating the GBU-15 Modular Guided Weapons System (MGWS) program and developmental concepts. The GBU-15 MGWS program is an on-going effort within the Air Force which is in the process of developing and integrating subsystems into a modular weapon system. This system has been designated the Modular Weapon Program (MWP) baseline. The current baseline configuration and other modules which may be added in the future will be integrated by means of a digital autopilot.

The development and demonstration of the Programmable Digital Autopilot (PDAP) for the GBU-15 MGWS, and the digital processor (DP) for developmental weapons was accomplished under the Digital Guided Weapons Technology (DGWT) program at the Air Force Armament Laboratory. Using the PDAP as the integration device for GBU-15 has had a profound impact on the management aspects of that program. Likewise, the probable use of the DP to support and integrate standoff weapons of the future will significantly influence the acquisition process. This study will focus on the current and planned use of digital integration within one Service. However, the nature and extent of tri-Service involvement in the development of digital processors for tactical guided weapons will be discussed later in the report. The scope of this effort is not to examine all the management tasks associated with the acquisition process, but to address only those directly affected by digital technology. Ultimately, the writer hopes to establish firm considerations for those who may eventually manage a major weapon system involving digital integration.

SECTION II

BACKGROUND

In an effort to reduce life cycle cost and improve weapon system integration, the Air Force has studied modular air-to-surface guided weapons during the past six years. The concept originated with the Modular Bomb Study, conducted by the Air Force Armament Laboratory (AFATL) during the latter half of CY 1970. This effort was expanded to include guided weapons as well as free fall ordnance.

Beginning in 1971, these results were amplified by three contracted "Concept Formulation Studies." The results of these studies clearly indicated that the modular approach was feasible and that there was a potential for significant cost reduction.

In order to broaden the data base, three contracts were let to begin the aerodynamic configuration and component definition of a modular family based on the AFATL concept definition. These efforts, conducted during 1972 and 1973, were amended a number of times as new study requirements were identified by the Air Force. Most significant of these was a study to define in detail the interfaces between a universal autopilot, a variety of seekers whose detailed characteristics were specified by the sponsor and the aircraft avionics associated with an F-4E and A-7D which are Maverick capable. Since nearly all the seekers and the aircraft avionics had analog interfaces, the autopilot was configured as an analog device. The study produced a wealth of data on the problems of modularity and analog integration and identified promising solutions. Among these was the need to develop a programmable digital autopilot to meet the spectrum of mission requirements and to provide

a baseline for investigating the interface problem. Recent work in digital stores management systems (SMS) and the Digital Avionics Information System (DAIS) indicates that a digital processor in the weapon may ease the aircraft/weapon interface problem as well as provide the flexibility required of the programmable autopilot.

During 1972 AFATL sponsored a program to evaluate the application of digital technology to tactical weapon autopilots. These studies resulted in the definition of a digital autopilot with the capability of being programmed to control and steer any lock-on-before-launch guided weapon. The simulation and sensitivity analyses indicated that the weapon performance, with the defined digital autopilot, was unchanged from that obtained with an equivalent analog autopilot.

In 1974 the AFATL sponsored the DGWT program. The objectives of this effort were (1) to define digital integration design requirements, (2) to design, fabricate and evaluate a PDAP for the GBU-15 MGWS and (3) to develop and evaluate a DP for future weapons application. The technical feasibility and cost effectiveness of the PDAP were clearly demonstrated in 1975, and that portion of the advanced development effort has been transitioned to the GBU-15 SPO. The digital system design requirements were used as a baseline to design and fabricate a DP for laboratory test. Two units are currently being evaluated in the performance of processing functions associated with the flight control, the strapdown inertial measurement unit (IMU), system management, aircraft interface and the support and integration of selected guidance units. The results to date are highly satisfactory and the contract should be completed in late 1976.

So far the author has attempted to show the logical progression of digit-

al technology in tactical guided weapons. In subsequent sections the idea of digital integration will be expanded into a management concept and evaluated using the GBU-15 MGWS program.

Why Digital Integration

The 1973 Mid-East War pointed out the increased tactical utility of guided weapons. It also pointed out the need for increased standoff in the face of an expanded ground base air defense capability. In order to exploit the lessons learned from this conflict, the Chief of Staff directed a high priority program called Pave Strike with the objective of further improving our conventional fighting capabilities. The guided weapons being developed under this program were the GBU-15 MGWS and the Imaging Infrared Guidance unit for the Maverick missile. Subsequent direction was received to incorporate as much modularity and commonality into these weapons as practical within the constraints of cost and schedule.

The user has also stated a desire for a greater variety of weapon options to counter the anticipated threat under the entire spectrum of operational conditions in poor weather and varying degrees of anti-aircraft defenses. However, he recognized the complexity and cost of continued proliferation of dedicated systems, with their burden on the logistic, training and support systems. He has also expressed concern about the number of aircraft which are dedicated to a single munition or group of munitions by their avionics suit and their impact on the force structure. He has also expressed a desire for a reduction of the number and skill level of the personnel supporting these systems.

In view of these requirements, it has become necessary to reevaluate the basic concepts of weapon development. Most of the air-launched tactical

weapons, which are operational today, are implemented with analog electronics. Typically, there are computational and logic functions in many of the interfacing subsystems. By nature of their design, however, each subsystem is capable of performing its particular functions independently. Frequently, these functions are not required concurrently, hence, much of the electronics are unused during significant portions of the mission. This leads to inefficient utilization of the available resources. Furthermore, the analog system is highly susceptible to the propagation of spurious signals throughout the various interfacing subsystems, leading to substantial difficulty during system integration. Each piece of analog hardware is unique to the particular task for which it was designed. The development effort required to produce a qualified module is costly even if proven components are employed due to problems of Electro-Magnetic Incompatibility (EMI), ground loops, environmental/stresses and buildup of tolerances. Even when design margins are high, an inadvertent change to some element of the system may cause repercussions in other areas leading to costly redesign and requalification of the hardware to achieve compatibility. This conventional approach has little potential for flexibility or modularity.

Digital integration presents a much more practical solution. By centralizing computation functions in a digital processor, the overall computational load can be managed with much greater efficiency. Prelaunch checkout, parameter initialization, midcourse guidance, terminal guidance, fuzing, fuel management and autopilot computations can all be handled by the same processor since they do not occur concurrently. Figure 1 illustrates this concept of system integration through digital processing. Although there are many different kinds of guided weapons, fulfilling many types of missions, each

SYSTEM INTEGRATION BY DIGITAL PROCESSING

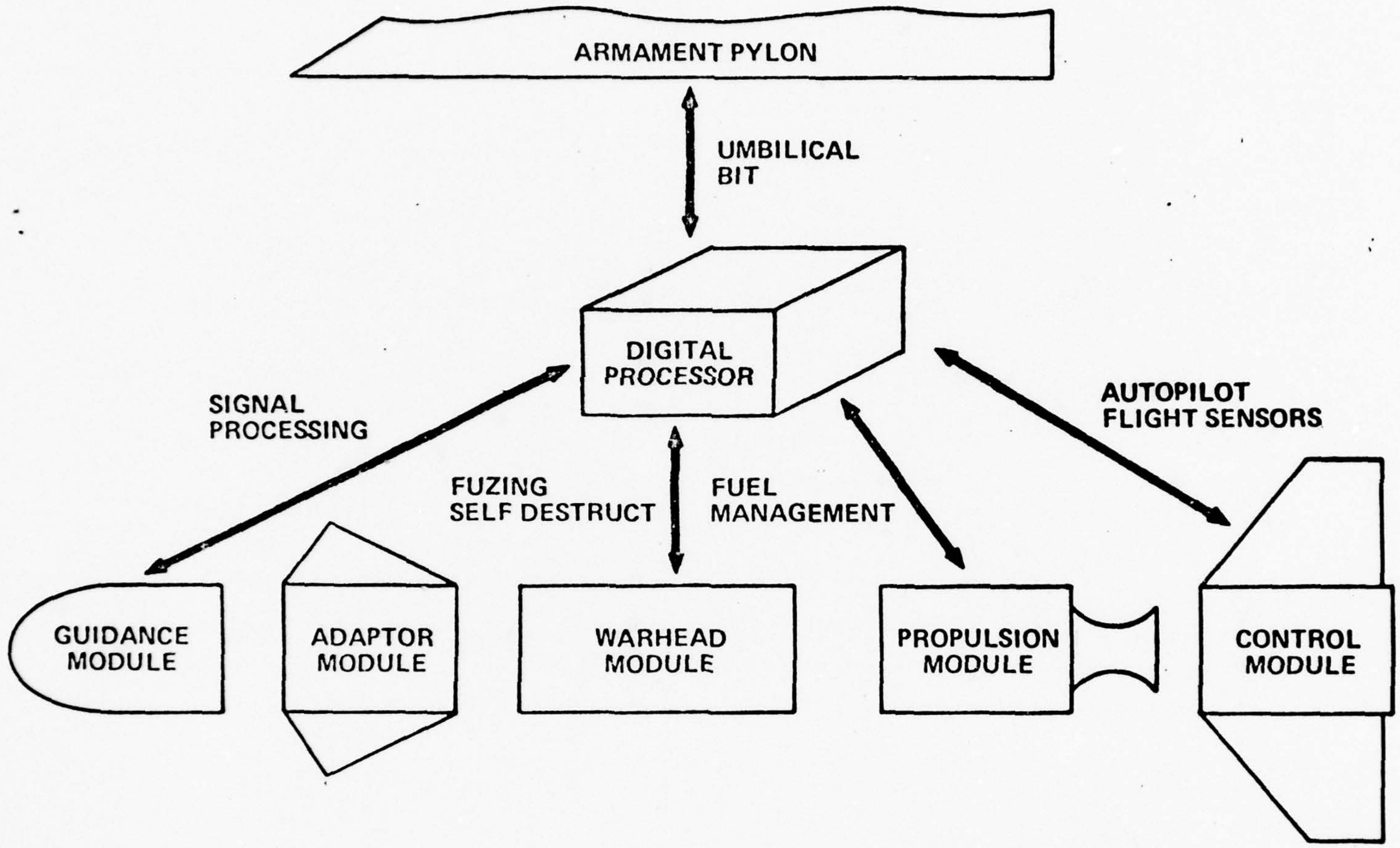

Figure 1

is composed of the same collection of basic functional blocks or modules. It has been acknowledged for years that the computations associated with the functional modules, such as guidance signal processing, could be performed digitally. However, little was accomplished, outside of studies, toward the goal of allowing a single programmable processor to be used with several different weapon system combinations of different versions of the same basic functions until the DGWT and GBU-15 programs at the Armament Development and Test Center (ADTC). These efforts demonstrated that the basic requirements are to have the necessary memory to store the instructions for the various computational loads and an executive program to assign the computing capability to the specific subsystems as required. When communication between subsystems is by common digital format, the interfaces are easily controlled. Integration can now be achieved through software, providing maximum flexibility. Since the aircraft avionics are moving towards a complete digital format, the digitally integrated weapon can directly communicate with the avionics computer, greatly enhancing the quality and quantity of prelaunch information which may be readily provided to the weapon.

Digital integration promises substantial cost savings in development by permitting the use of qualified hardware in new applications through software programming. Substantial cost savings are also seen in production since general purpose hardware can be used in a wide variety of applications, thus benefiting from high rate production. Flexibility in applications can be achieved by expandability through the use of add-on memories and multiprocessor usage. Cost savings may be realized during the maintenance/operational phase since product improvement and/or corrections of deficiencies may frequently be achieved through simple software modifications.

Computer hardware is currently available as complete subsystems or as major components which may be assembled into digital processors which more closely meet the specific user requirements. Advances in LSI (Large Scale Integration) digital circuitry have made the digital approach attractive from a cost, size, and power consumption standpoint. The cost of analog components is increasing while the cost of digital components is decreasing. In addition, technological advances can be incorporated into the weapon without obsoleting the entire system. Further advances in solid state electronics technology are expected to increase the speed and capability of these devices and result in cost decreases as additional uses are found.

Both from the acquisition and user viewpoints, there appears to be many distinct advantages for employing digital integration in tactical guided weapons. The effects on the management of systems which are being integrated digitally will be discussed in Sections III and IV.

Management Considerations

Kast and Rosenzweig in their text on Organization and Management have stated:

> "In many ways, the impact of technology on the managerial system has been even more dramatic than on the other organizational subsystems. We marvel at the obvious technological advancements required to send men to the moon and return them safely. However, the managerial skills required to plan for and integrate all the diverse activities for successful mission accomplishment are equally important. The improvements in management techniques in the United States have perhaps done more to revolutionize society than have scientific-engineering changes."

There is little doubt that the managerial system in the quotation refers primarily to the broad processes and concepts that evolve within a large organization such as NASA. However, it is the opinion of the author that the idea applies equally well to the concept of modularity as a management

system for a tactical weapon inventory. Several reports have been written on the evolution of the Modular Weapons Program (MWP) and the integration problems associated with such a system. The intent of this report is to increase that body of knowledge by evaluating the impact of digital technology on the GBU-15 MGWS and future developments.

In considering the spectrum of weapon system acquisition there are a number of areas directly affected by the application of digital integration. The first is life cycle costs. Can a direct comparison be made between a system using either analog or digital componentry? Which will be more cost effective in a baseline program and in the far term when new modules are added to the system? What are the provisions for growth and flexibility and modularity?

The second area is that of logistics training and maintenance. When and where should the operational flight program be placed in memory? This could be done at the plant during development or at the storage depot or in the field depending on how much flexibility is built into the system. What is the effect on training? Should personnel be trained to reprogram the weapons on the flight line? What will be the overall maintenance concept? Will fault isolation be at the "black box" or printed circuit board level?

The third general area for consideration is software management. This is a new dimension that is added with a digital system. Software programs must be tracked and maintained as changes are made to the system. The programs must be verified for accuracy when integrated with the system hardware. Should weapon software be developed and acquired in the same manner as avionics software? What are the differences and how do they effect the development process?

The fourth area is procurement strategy. With a digital processor in the weapons, the sponsor is in a unique position to control the interfaces within the weapon and externally between the weapon and the aircraft pylon. What will be the effect on business strategy? Should the Service provide the interface control specifications on the digital processor system as a "design to" requirement for module (i.e. guidance unit) procurement? Will the contractor who develops the processor remain the integrator for the life of the system?

The fifth area for consideration is tri-Service Application. Plans have been formulated in DOD to control the proliferation of digital processor development for guided weapons. Can these units be interchangeable between weapon systems? Will a general purpose processor satisfy requirements in the three Services and still remain cost effective? Does one design for the "worst" case conditions?

No attempt will be made to answer all these considerations at this time. However, they should serve as a reminder as to the types of requirements that must be addressed when managing a digitally integrated system. A detailed treatment of each area will follow with an evaluation of the GBU-15 system and future concepts.

SECTION III

THE GBU-15 CASE

Prior to evaluating the management issues associated with digital integration, it is necessary to understand (1) what is meant by the modular concept, and (2) the modularity aspects of the GBU-15.

The Modular Concept

The GBU-15 MGWS is composed of a large family of modules which can be assembled into various specific weapon configurations. The modular weapon development approach to system acquisition develops standardized sets of weapon components which can (1) be used in various combinations to provide effective weapons for given tactical target and attack situations, and (2) provides a mechanism for the systematic upgrading of weapons by incorporating new technology in modular form instead of as a complete new weapon.

There is not a simple, direct one-for-one correlation between a given module and a specific weapon configuration. The program has dual development objectives; weapon module design and specific weapon configuration. The weapon module development objective is required as a new technology, e.g. Laser and Imaging Infrared (IIR) guidance are infused into the program. Additionally, the elements required to build up a specific weapon configuration are developed and procured as modules. On the other hand, to satisfy operational requirements, specific configurations are levied on the program. Also, testing is accomplished in terms of specific configurations.

Figure 2 correlates the "modular" aspect with the "specific weapon configuration" aspect of the total program. The major modules that are in various stages of development are listed on the left. In some instances,

GBU-15 MODULAR CONCEPT

MODULES	WEAPONS	CWW								PWW						
		MK-84				CBU-75				MK-84				CBU-75		
		TV	TV/DL	TV/DL/DME	DME	TV	TV/DL	TV/DL/DME	DME	TV/DL	TV/DL/DME	TV/DL/BCN	DME	TV/DL	TV/DL/DME	DME
BASELINE	TV GUIDANCE	P	P	P		P	P	P		P	P	P		P	P	
	GUIDANCE ADAPTER	P	P	P	P	P	P	P	P	F•	F•	F•	F•	F•	F•	F•
	CONTROL	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	BATTERY	P	F•	F•	F•	P	F•	F•	F•	F•	F•	F•	F•	F•	F•	F•
DME GUIDANCE	WEAPON GUIDANCE SUB-SYSTEM			P	P			P	P		P		P		P	P
	SYNTHETIC VIDEO GENERATOR				F•				F•				F•			F•
	DV GYRO		F•	F•	F•		F•	F•	F•	F•	F•	F•	F•	F•	F•	F•
WING FORMS	CRUCIFORM WING	P	P	P	P	P	P	P	P							
	PLANAR WING									F	F	F	F	F	F	F
WARHEADS	MK-84	P	P	P	P					P	P	P	P			
	CBU-75					P	P	P	P					P	P	P
DATA LINK SYSTEM SEGMENT	AIRCRAFT DATA LINK		F	F			F	F		F	F	F		F	F	
	AIRCRAFT DL KIT		F	F			F	F		F	F	F		F	F	
	WEAPON DATA LINK		F•	F•			F•	F•		F•	F•	F•		F•	F•	
	BEACON											P				
FUZE	FMU-124/B	F	F	F	F					F	F	F	F			
	LAPS			F	F							F	F			
	FMU-123/B					F	F	F	F					F	F	F
AEROSPACE GROUND EQUIPMENT	GROUND HANDLING EQUIPMENT	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	SHOP MAINTENANCE TEST SET	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	AIRCRAFT SYSTEM TEST SET	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	AIRCRAFT DATA LINK TEST SET		F	F			F	F		F	F	F		F	F	
	WEAPON DATA LINK TEST SET		F	F			F	F		F	F	F		F	F	

P= PRODUCTION PHASE

F= FULL SCALE DEVELOPMENT PHASE

F•= FSD PHASE COMPLETED

Figure 2

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modules are lumped together into a second tier description, e.g. baseline module, when the modules are consistently used together. The major weapon configurations are listed across the top of the page, and at the third tier are shown to fall into one of two generic categories, e.g. planar wing weapon (PWW) and cruciform wing weapon (CWW).

The matrix shows which modules are combined to make up a specific configuration and it shows the development status of each module. A module which is defined as being in production (P) is procured with funds appropriated for procurement (3,080 dollars). A module which is defined as being in full scale development (F) is financed with funds appropriated for research, development, test and evaluation (3,600 dollars). Inherent in the module concept is a funding aspect which has caused confusion; that a weapon configuration comprised of modules, each of which may be in various stages of development (R&D and Production) requires a concurrent use of production and RDT&E funds. However, at no time will there be a configuration in the inventory or in production which is funded through both appropriations.

Modularity Aspects of the GBU-15

Figure 3 depicts the modularity aspects of the GBU-15. The system includes two wing modules, cruciform (CWW) and planar (PWW), which, when combined with a warhead and appropriate baseline modules, provide two distinct aerodynamic configurations. The CWW was designed primarily for the role of low altitude direct attack, whereas the PWW was designed primarily for high altitude standoff. Figure 3 also shows the two warheads for the GBU-15. The MK-84 has three fuze modes. They are instantaneous, delay and low altitude proximity. The SUU-54 has only one associated fuze--the FMU-123--for opening the dispenser at an altitude sufficient for proper submunition

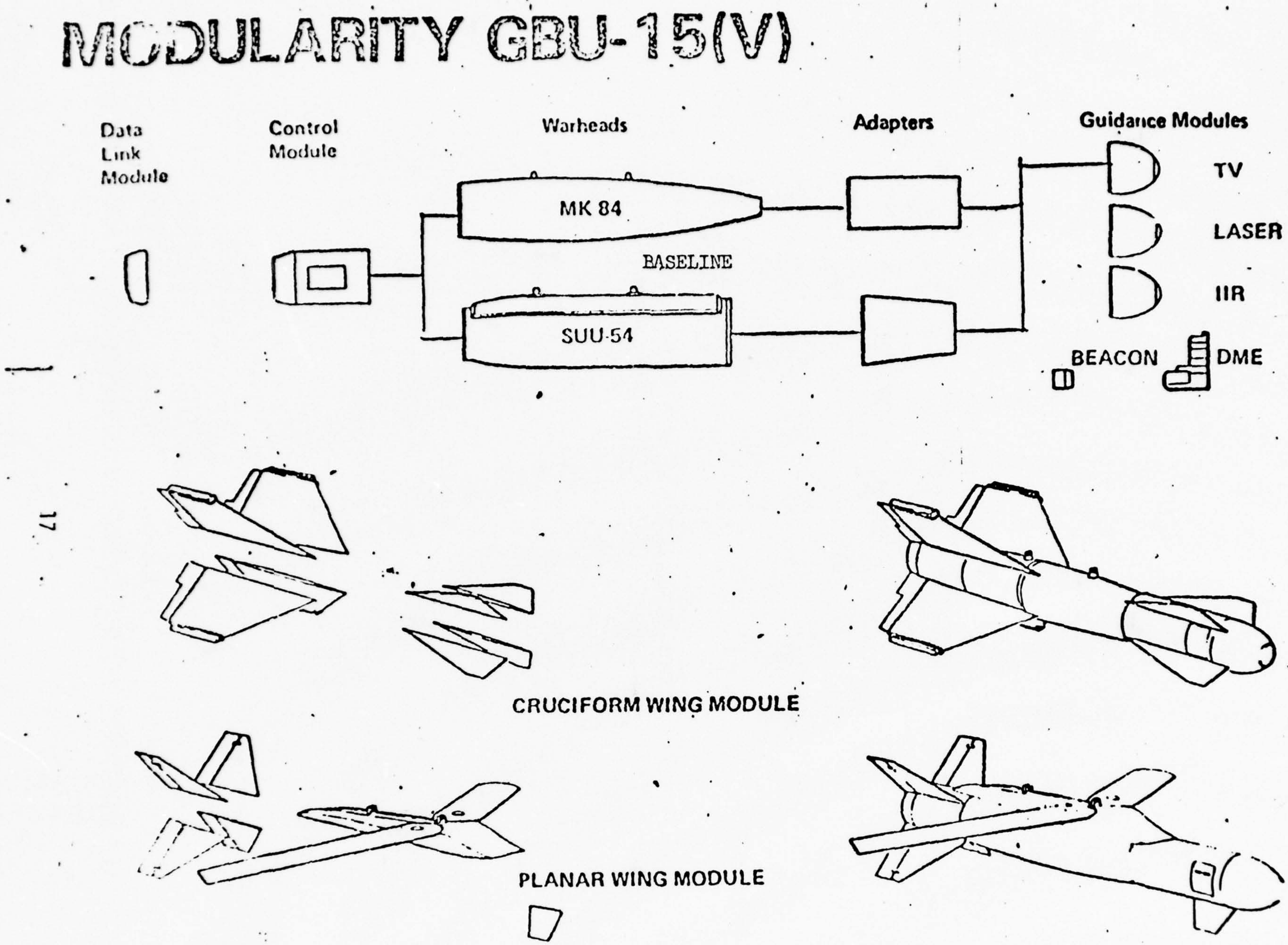
MODULARITY GBU-15(V)
Data Link Module
Control Module
Warheads
MK 84
BASELINE
SUU-54
Adapters
Guidance Modules
TV
LASER
IIR
BEACON
DME
CRUCIFORM WING MODULE
PLANAR WING MODULE

Figure 3

dispersion. The baseline program currently uses TV, Distance Measuring Equipment (DME) and a Beacon in various guidance combinations. The LASER and IIR modules are in development and may be added to GBU-15 at a later date.

Weapon Control Unit

The concept of modular weapons which tailors a weapon to a particular mission, required that the modules (Figure 3) be integrated with control from a central processing unit. The ability of accomplishing such a function with dedicated analog circuitry, and providing the necessary flexibility without hardware change for each possible combination is prohibitively expensive. The programmable aspect of a digital processor was seen as an ideal method of accomplishing the integration function.

The AFATL conducted a competitive procurement from nine responsive contractors to develop a Programmable Digital Autopilot (PDAP). Hughes Aircraft Company was selected for the development program to verify by brassboard hybrid simulation test that GBU-15 requirements could be met. The GBU-15 program office monitored the progress of this development and provided some additional funding in FY 75. This was to insure that GBU-15 PWW requirements could be met prior to committing to the FY 76 FSD of the PWW. This laboratory development program demonstrated the feasibility of using digital processing for GBU-15 applications. The results show that such a device is cost effective when compared to an analog autopilot, can accomplish all the present GBU-15 requirements, and accommodate growth provisions for laser, IIR, Pave Tack initialization and Laser guidance.

Backed by these results, the Air Force made the decision to incorporate a similar digital processor into the GBU-15 as a Weapon Control Unit (WCU).

The WCU will perform many more functions than a simple autopilot. It will provide mission logic and sequencing functions, provide the necessary stability and control functions, and provide guidance implementations necessary for the accomplishment of the weapon's mission. Mathematically this is represented by WCU = PDAP + Non-Autopilot Functions. In addition, it will function such that the capability of the CWW is not modified nor reduced by the utilization of the WCU as a direct plug-in replacement for the current analog autopilot. The WCU is being designed to sense the configuration which the weapon is in to determine subsequent operational modes. The connection of each module into the weapon will supply an identification signal which enables the WCU to determine the configuration. Once the weapon configuration is identified the WCU accomplishes all control and sequencing functions necessary to fly the vehicles to the target. Growth potential (memory and processing speed) is provided for a laser seeker with lock-on before launch (LOBL) and lock-on after launch (LOAL) capabilities, the IIR seeker and LORAN modules.

In summary the full scale engineering development program for the PWW will consist of (1) the development and integration of the digital WCU into the baseline module, and (2) the associated development and integration of the planar wing module (PWM) with the baseline module to provide a standoff configuration against both fixed and moving targets.

Management Issues

In a Memorandum For the Assistant Secretary of the Air Force (R&D) on GBU-15, Mr. Robert N. Parker, Principal Deputy to DDR&E stated that:

> "The costs projected for integrating sensor modules into the GBU-15 weapons and procuring the weapons for inventory seem excessive. Unless we can find ways to reduce the cost of qualifying seekers, guidance modules, etc. into

the GBU-15 family and buy selected modules in an efficient way, the concept of "modularity" loses viability. The following is a list of changes and additions I wish the Air Force to implement to reduce and control costs of the GBU-15 program:

-Seek ways to reduce the cost of integrating and testing the laser and imaging infrared sensors being developed under the Maverick program into the GBU-15 and report the results prior to the GBU-15 DSARC in November 1976.

-Identify the most cost efficient procedures for budgeting, procuring, and handling the GBU-15 weapon family in inventory. It may be that procuring certain modules in greater numbers or at faster rates than we buy MK-84's or SUU-54's is appropriate and we must start now to make that possible. My staff will work with the Air Force to identify DOD or Service Directives that appear to cause problems."

It is certainly beyond the scope of this paper to investigate and offer solutions to all of the identified problem areas. However, the author feels that a significant step was taken to reduce the cost of module integration through the funding and development of the digital WCU. The relative merits of using digital integration to reduce the cost of the GBU-15 program is illustrated in Table 1. Listed on the left are the basic parameters that are used for comparison purposes. In this case, interest is centered on the use of either digital or analog technology and the impact on GBU-15 autopilot development. The autopilot was chosen because it is the "brain" of a guided weapon. It accepts the sensor data inputs, performs the necessary calculations based on those inputs and the resident guidance laws, and sends the resulting information to the control section so that unit can react to steer the weapon.

Close investigation of the data contained in Table 1 reveals that (1) for tactical guided weapons digital technology has distinct advantages over analog circuitry, (2) every change or addition to the weapon directly or indirectly affects the autopilot, (3) the integration process can be controlled through software change in the digital autopilot, and (4) the use of digital technology

TECHNOLOGY COMPARISON

IMPACT ON GBU-15 AUTOPILOT DEVELOPMENT

PARAMETERS	DIGITAL	ANALOG
R&D Direction	Allows incorporation of modularity and commonality in weapon systems.	Allows only dedicated hardware.
User Requirements	Allows a variety of weapon options to counter the anticipated threat.	Complexity and continually rising costs due to proliferation of dedicated systems.
System Integration	Through software change.	Through changing analog circuitry components and recalibration (prohibitively expensive).
Growth Potential	Accommodates baseline program plus provisions for Laser, Pave Tack, IIR, LORAN.	None. Autopilot area completely utilizes.
Operational Flexibility	All program options contained in software; changes in mission via ident. signal to memory.	No changes allowed from preset parameters (inflexible).
Simplifies Logistics	One weapon control unit (WCU) for all GBU-15 configurations.	Two required, one for CWW, one for PWW, and additional versions are needed for new modules.
Reduced Stockpiling	One WCU, factory installed, to support.	Two or more autopilots to support.
Field Assembly	One WCU, self-contained with all configurations preprogrammed.	Separate autopilots for both weapons--need to calibrate and adjust.
Reliability	Inherently high for digital systems.	Less reliable.
LCC (PDAP vs. Analog)	PDAP increasingly cheaper as new modules added (see Figure 6).	

Table 1

TECHNOLOGY COMPARISON
IMPACT ON GBU-15 AUTOPILOT DEVELOPMENT

PARAMETERS	DIGITAL	ANALOG
Technology	Digital LSI circuitry available (reduced cost, size, power consumption).	Component cost increasing.
Aircraft Interface	Aircraft avionics digital/WCU allows digital to digital interface with avionics computer.	Costly aircraft modifications each time a new system is added to the inventory.
Technological Change	Can be incorporated into the aircraft and weapon without obsoleting the system.	New changes are cost prohibitive, analog technology obsoletes the system.
Flight Profile	Optimizes trajectories, maximizes range and effectiveness.	Limited to preset value, does not compensate for weapon reconfiguration.
Function	WCU performs more than autopilot function (i.e. Pave Tack Initialization, LORAN guidance computation, self check, data link decode, etc.	Limited strictly to autopilot functions.
Trend	Aircraft avionics, navigation and communication systems are all going digital.	Less system usage.
GBU-15 Experience (Changes in wing surfaces and wiring)	In WCU, software would have accommodated the changes.	In CWW, requires circuit board modification resulting in excessive costs.
Procurement	Allows the Air Force to control the interfaces and reduce integration costs.	Dedicated hardware--allows the contractor to control reprocurement of the system.
Tri-Service Application	Digital processors can be used on weapon systems across the Services.	Each development perpetuates dedicated hardware proliferation.

Table 1 (Continued)

in guided weapons may require special considerations and unique management procedures. Based upon these observations, this study will now involve a detailed assessment of five major areas within the GBU-15 program which are most affected by the digital integration process. These are Procurement-Future Programs, Life Cycle Cost Analyses, The Logistics/Maintenance Philosophy, and Software Management.

Procurement-Future Programs

Initial Pave Strike direction required priority action to develop a standoff weapon capability. Air Force resources were used to determine the best business management approach to meet the critical needs. The initial acquisition approach resulted in the Air Force acting as a prime contractor to integrate the various carrier and module assemblies to produce standoff weapons with myriad performance capabilities. These initial decisions have reduced the program's fund requirements by not having a prime contractor with total performance responsibility. On the other hand, the acquisition approach has relied on two main contractors as systems integrators, namely, Rockwell (MSD) for the CWW and more recently, Hughes for the PWW.

As the various modules of the GBU-15 program have emerged, it has become apparent that some degree of prime contract management is necessary to assist the Air Force in its integration role. The principal associate contractor (Rockwell International Corporation) has served in this role primarily in developing interface specifications, standards, and maintaining configuration control through its chairmanship of the GBU-15 Interface Control Working Group (ICWG) which consists of all Air Force associate contractors. Since a prime contractor does not exist, responsibility for system integration rests with the Air Force.

Based upon experience from the CWW, action has been taken in the PWW FSD program to utilize Hughes not only as the integrating contractor but also as a prime contractor with Celesco as the subcontractor for the planar wing module. A secondary reason for selecting Hughes was their participation in the development and demonstration of the digital autopilot. The digital unit (WCU) will replace the analog autopilots in the GBU-15 and serve as the "integrating component" for both current and future modules. In the GBU-15 program the need for digital integration has directly influenced the selection of a prime contractor for the PWW. In addition to the technical and management advantages of this action, three other resulting benefits are (1) competition is now established between the prime system integrators, (2) better contractual balance is now established in the programs, and (3) the prime integrator role relieves the sponsor of solving system integration problems in a tight DOD manpower environment. On the negative side the sponsor may become "locked-in" with the contractor who produces the integrating module, which is the digital autopilot in the GBU-15 weapon system. This could prevent competition in the future when additional modules are added to the system, and allow the single contractor to increase his prices in the non-competitive environment.

As the future modules are developed, decisions must be made on a case-by-case basis to determine whether the module will be placed under a prime integrating contractor, subcontractor or be provided to the integrator by the Air Force as GFE. The above decisions will have to be based upon cost effectiveness, technical risk, and interface complexity. The preferred method for adding modules to the CWW and PWW would be through a prime/subcontractor relationship using the digital integration properties of the WCU. Maximum use of prototype fly-offs at the subcontractor level with Air Force surveil-

lance of the prime contractor's selection procedures should be used to foster competition at the module level.

Life Cycle Cost Analyses

The second area that is significantly impacted by digital integration is that of life cycle costs. This can best be demonstrated by summarizing a life cycle cost comparison between the PDAP and the analog autopilots for the GBU-15 weapon system. Table 2 indicates the primary cost elements included in the life cycle cost model and a typical tabulation, relating the cost elements to the number of weapon reconfigurations (6:142).

The life cycle cost model scenario assumed 10,000 weapons (each with its own digital processor) deployed at a number of bases over a ten-year period. It was assumed that operational requirements would change during that period and that each change would require at least one-half of the memory to be reprogrammed. The effect of the reprogramming was treated parametrically with 1, 2, 3, or 4 reprogrammings required during the ten-year deployment.

Three memory options and two fabrication options were considered:

(1) Read-only memory (ROM); programmed at fabrication.

(2) Field programmable read-only memory (PROM). This can be programmed at the factory, at the depot, or in the field.

(3) Reprogrammable memory that can be reprogrammed in the field.

Fabrication options were:

(1) Hardwired circuit boards.

(2) Circuit boards with memory mounted in sockets.

The ten-year costs for the three memory options are shown in Figure 4. The ROM option was evaluated with throwaway boards, hard-wired boards on which ROM's were replaced, and boards designed with socket mountings to accept the

Table 2. Life Cycle Cost Model Elements

COST ELEMENTS	NUMBER OF WEAPON RECONFIGURATIONS				
	0	1	2	3	4
RDT&E	2500.0	2500.0	2500.0	2500.0	2500.0
PRODUCTION					
IMPLEMENTATION (TOOLING)	25.0	25.0	25.0	25.0	25.0
MFG (ORIGINAL DESIGN)	25440.0	25440.0	25440.0	25440.0	25440.0
CHANGES (WPN RECONFIG)					
HARDWARE REDESIGN	–	0	0	0	0
SOFTWARE REDESIGN	–	6.0	12.0	21.0	33.0
HARDWARE COST					
ROMs	–	119.6	281.1	320.5	371.2
CIRCUIT BOARDS	–	0	0	0	0
OTHER	–	1.9	3.5	4.2	6.3
OTHER INVESTMENT					
TEST EQUIPMENT	NO UNIQUE TEST EQUIPMENT REQUIRED				
SUPPORT EQUIPMENT	0	0	0	0	0
INITIAL TRAINING	NO UNIQUE REQUIREMENTS EXIST				
MANUALS AND TECH DATA	11.0	11.0	11.0	11.0	11.0
TEN YEAR DEPLOYMENT					
SPARES AND REPAIR PARTS	842.6	870.0	934.0	943.3	980.0
INTERMEDIATE MAINTENANCE	1.6	1.5	0.3	0.2	0.2
DEPOT MAINTENANCE	0.7	0.7	0.8	0.8	0.8
GOVERNMENT INSPECTION	8.4	9.9	12.2	12.7	13.6
SUPPLY SYS INTRODUCTION	14.6	23.0	31.3	39.7	48.0
SUPPLY SYS MANAGEMENT	41.6	46.9	53.5	58.7	58.7
PACK/SHIP REPAIRABLES	0.5	0.5	0.1	0.1	0.1
SECOND DESTINATION TRANS	AUTOPILOT SHIPPED AND STORED AS PART				
STORAGE	OF CONTROL SECTION. NO ADDITIONAL COST				
REPLACEMENT TRAINING	NO COST				
BASE ADMINISTRATION	0.7	0.8	0.8	0.9	0.9
($K)	28886.7	29056.8	29305.6	29378.1	29468.8

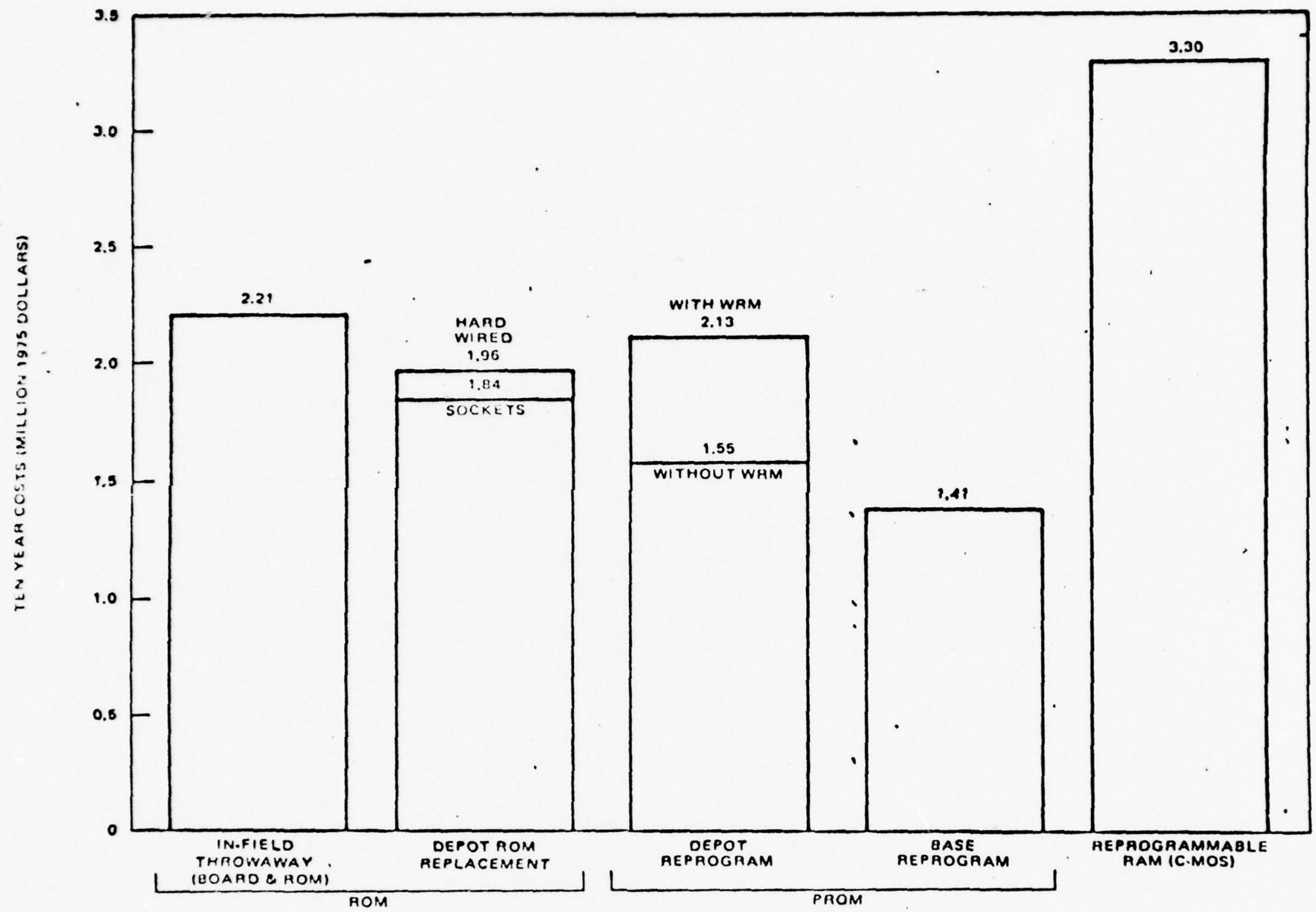

Figure 4. Memory Implementation Summary Cost Comparison

replacement ROM. The field programmable read-only memory (PROM) was evaluated where the reprogramming was done at the depot with and without a war readiness material (WRM) inventory; and in the field without a WRM inventory. The reprogrammable memory (CMOS) cost is illustrated by the last bar.

Figure 5 illustrates the cost sensitivity to the number of weapon reconfigurations over a ten-year period for one case. The example is for ROM attached to a throwaway circuit board. The cost trends showed that ROM's are preferred over PROM's if few weapons reconfigurations occur. The breakdown number depends on several design, quantity, and logistic support factors. For this study the breakdown number fell between 2 and 3. There is very little cost difference between programming PROM's at the depot and programming them at the bases.

In consideration of the above, a cost effectiveness analysis was accomplished to determine whether digital or analog integration would be most appropriate in the GBU-15 weapon system. Cost estimates include unexpended RDT&E funds, procurement of 10,000 autopilots (for the analog version this ammounted to 5,000 for PWW and 5,000 for CWW), and ten-year operating and support costs. Scenario assumptions also include nine-years peacetime operation, war in the fifth year, and zero through four configuration changes. For GBU-15 this could amount to the additions of Pave Tack Laser, IIR, LORAN and Global Positioning System (GPS) guidance.

Figure 6 shows that in all cases the life cycle costs of digital integration is lower than analog. Percentage differences range from 8.7 percent no changes to 60.6 percent four changes.

Although these cost studies were undertaken in the context of a tactical weapon environment the cost effectiveness of digital integration may apply

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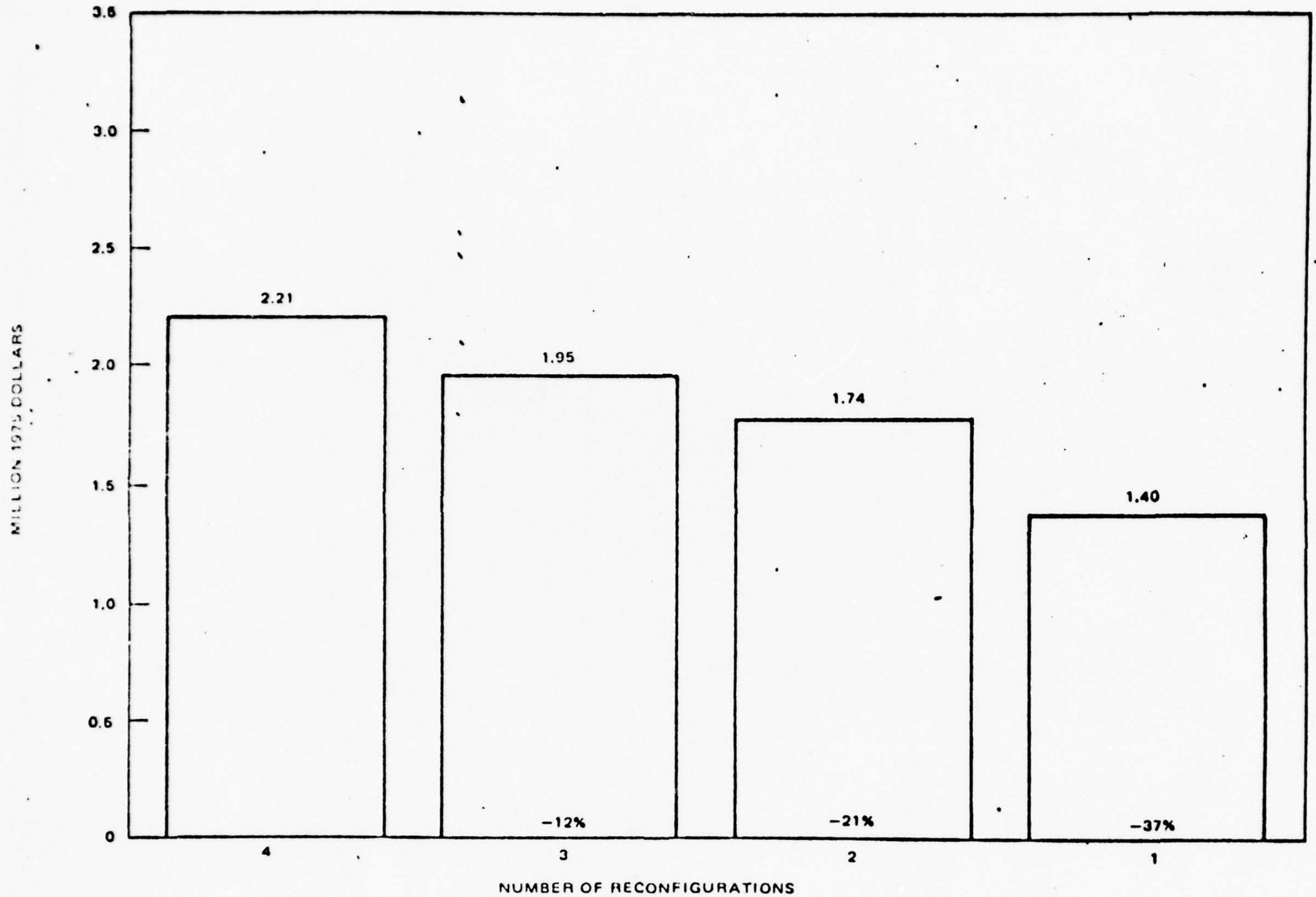


Figure 5. Scenario Cost Sensitivity

LIFE CYCLE COSTS

PDAP vs ANALOG AUTOPILOTS

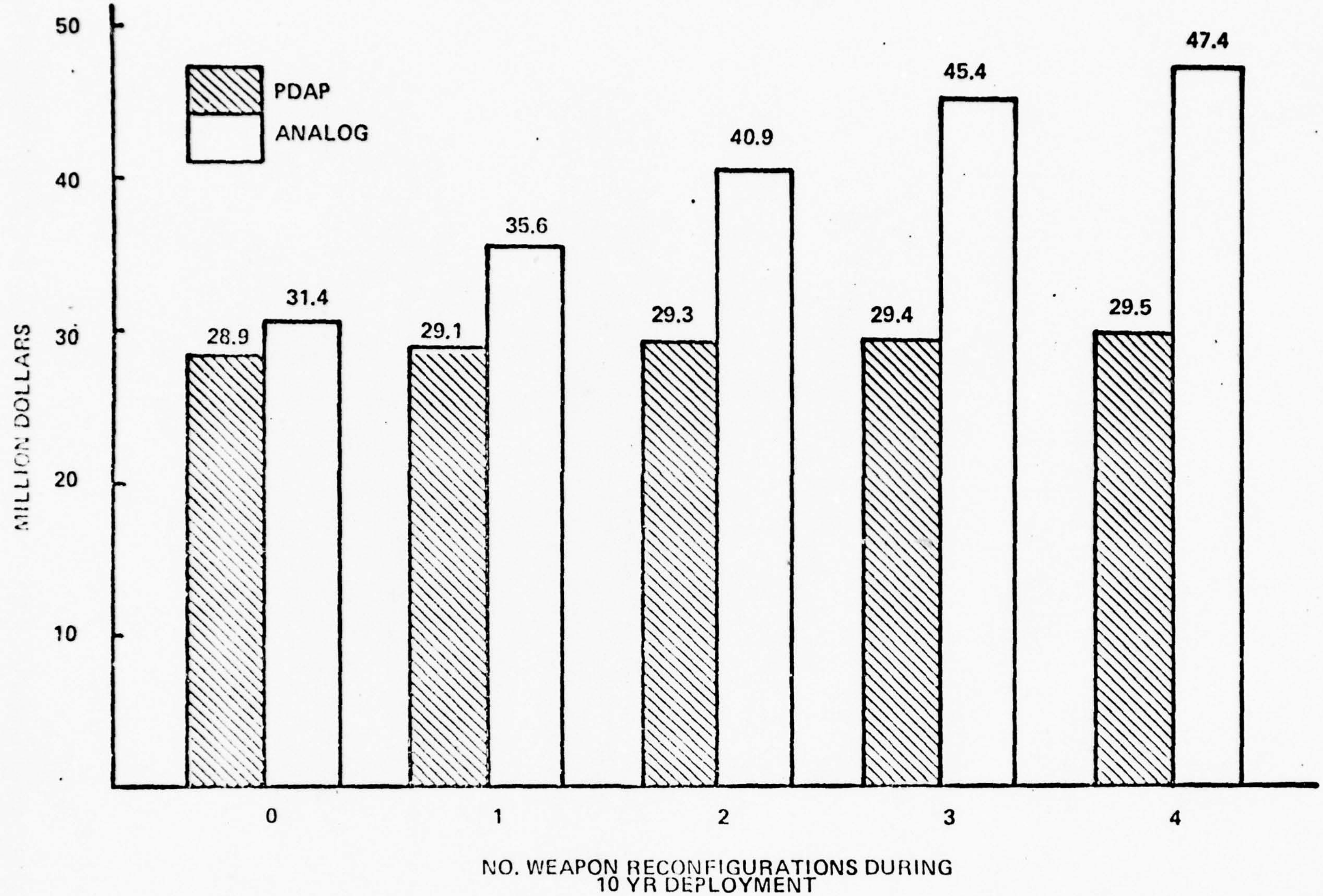


Figure 6

equally well to other DOD weapon systems. Program managers who are developing systems that will be subject to frequent update or change should consider the use of digital technology in reducing the total life cycle costs of that system.

Logistics/Maintenance Philosophy

The logistics/maintenance approach for the GBU-15 MGWS is based on the modularity concept. It addresses each module as an item which can be assembled in the field with various other modules to provide weapon configurations tailored to the operational environment. Each module is stored, transported, and handled independently as a component. The weapon is completely tested and checked out as a total unit; complex modules and major components are fault isolated independently. Fault isolation and replacement of most modules and replacement of failed components are performed at the field level. Technical data and field level support equipment are being developed to permit the accomplishment of maintenance tasks (fault isolation, repair and/or replacement) within one hour. Repair and calibration of support equipment are to be a user responsibility. The logistics support program which has been developed by the GBU-15 was strongly influenced by experience with the existing laser and TV guided bombs.

The maintenance plan for the GBU-15 is embodied in the approved (TAC, USAFE, and PACAF) Maintenance Concept issued on 6 January 1975. The Maintenance Concept has been included as a contractual guideline on each GBU-15 contract. It is also the basis for the maintenance philosophy contained in the draft TAF ROC dated 21 April 1975. SAC is presently reviewing the Maintenance Concept and, where necessary, modifications will be incorporated to support their command requirements. Detailed maintenance planning is

delayed pending a detailed concept of operation and employment, firm WRM quantities, number of units to be equipped, and specific deployment locations. As part of the total maintenance planning, Optimum Repair Level Analyses (ORLA), Life Cycle Test Planning, and detailed Logistics Support Analyses (LSA) can be selectively implemented as necessary.

The introduction of the digital autopilot into the GBU-15 program has has a profound effect on the logistics/maintenance planning for that system. Specifically, the possible methods of programming the autopilot must be taken into consideration. The alternative methods depend heavily on the type of memory, which may be ROM, PROM, or random access (RAM). Each memory configuration has different characteristics, and the program loading location (field, depot, or factory) is dependent to a large degree, on the type of memory selection. Another consideration is the option of developing a program for each existing weapon or developing one program for both versions (PWW and CWW).

The alternative programming concepts are outlined in Figure 7. Possible combinations involve factory vs. field programming, ROM vs. PROM vs. RAM and single vs. multiple programs. These concepts were presented at a meeting in March 1975 at Eglin AFB. The attendees (development, user, and training personnel) considered each path in view of the factors covered in Figure 8. General consensus was that having both programs resident in the memory simultaneously was the preferred approach (18:2-3). The idea of factory programming ROM's vs. field programming ability was discussed. The factory programming reduces logistic support problems, eliminates the need for additional support equipment (programmer-verifier), and eliminates necessary associated field program control procedures. However, the factory programming approach reduces the growth potential and flexibility of the digital autopilot in that the program memory

ALTERNATIVE PROGRAMMING CONCEPTS

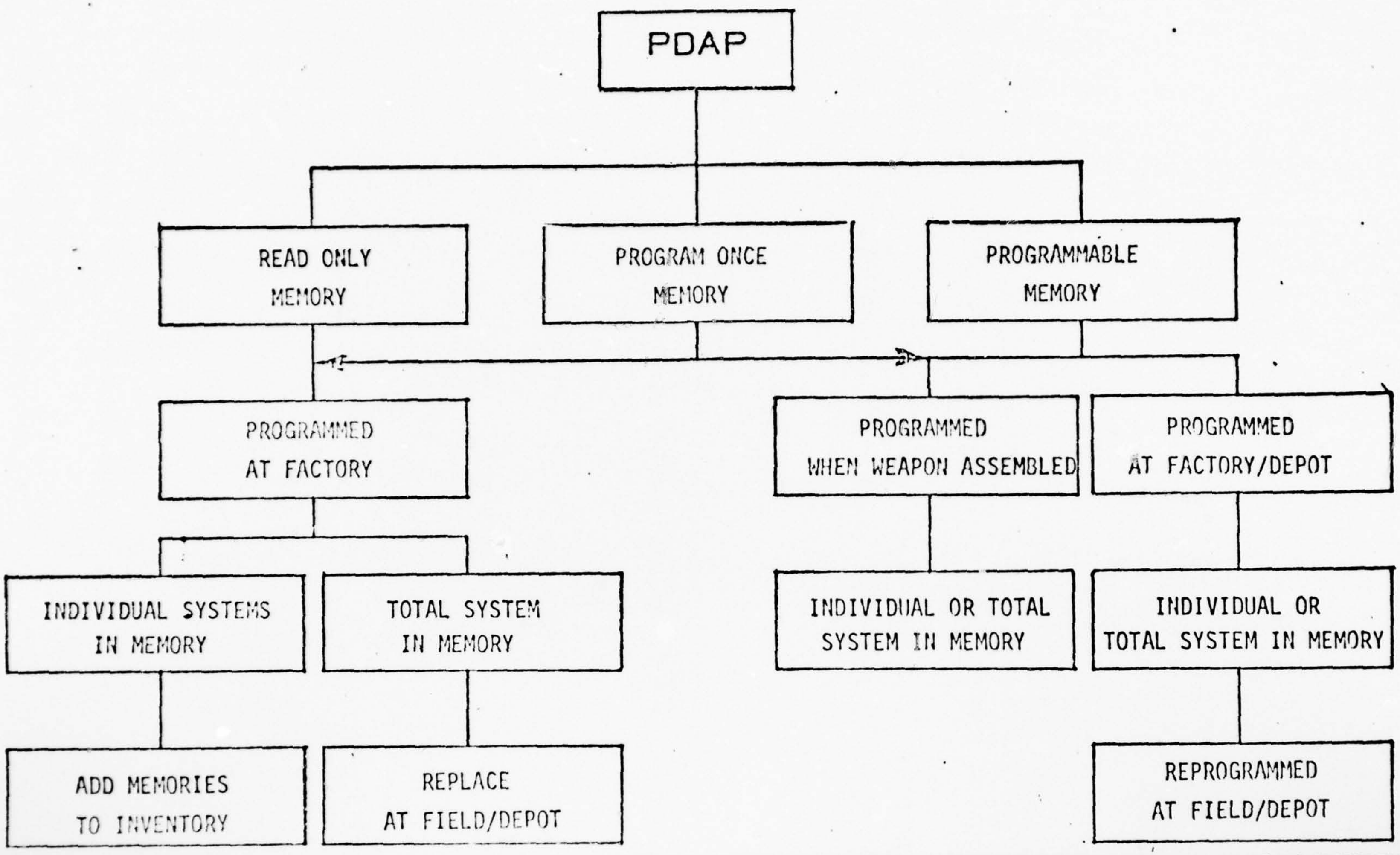


Figure 7

FACTORS TO CONSIDER

- RELATIVE RELIABILITY
- MODIFICATIONS TO EXISTING SHOP TEST SETS
- ADDITION TEST SETS AND ANCILLARY EQUIPMENT
- REQUIREMENT FOR MANUALS
- MAINTENANCE PERSONNEL TRAINING
- TOTAL INVENTORY REQUIREMENTS
- SOFTWARE COST - FREQUENCY & EXTENT OF CHANGES
- PACKAGING & TRANSPORTATION
- INVENTORY CONTROL PROCEDURES
- NUMBER OF OPERATING SITES
- GROWTH

Figure 3

ROM's would have to be physically changed to incorporate program modifications.

In order to further evaluate these concepts the author invited Dr. Willis H. Ware of Rand Corporation to attend a program review at the contractors facility. Dr. Ware's comments included the following:

> "The overall digital autopilot system must be designed so that no field intervention into the affairs of the computer is necessary. In particular, no field programming should be allowed, and ideally no field maintenance of the hardware permitted either. Any interaction between the digital autopilot and the modular weapon configuration should be accommodated automatically so that no flight-line adjustment is required to install the standard digital autopilot in a particular weapon."

Dr. Ware's assessment, additional trade studies by the contractor, and indepth GBU-15 SPO evaluation indicate that the programming concept for a tactical guided weapon should consist of (1) programs stored in ROM's, (2) programming at the factory, (3) all configurations in one integrated program, and (4) reprogramming should be done by module (semiconductor memory) substitution (23:2-3).

The programming concept for the GBU-15 MGWS illustrates the effect that digital integration has on logistics/maintenance planning. It applies equally well whether the digital device is a part of the weapon or a part of the test support equipment or both. Program managers should be aware of these considerations in the development of their systems especially where digital technology plays a vital role.

Software Management

One of the benefits obtained from the use of a programmable digital processor in a weapon system is that changes can be made in software, without changing the hardware configuration. This can very effectively extend the useful life of a weapon system without extensive hardware retrofit. However,

software costs are not insignificant. In some cases software costs have exceeded hardware costs in military systems using digital computers. Even in such cases the total system cost may be less than it would have been without a programmable processor. The point is that software costs can be very substantial and frequently exceed the first cost estimates.

Some of the reasons for excessive software costs are pointed out in a report prepared by the Institute for Defense Analysis; Electronics-X: A Study of Military Electronics With Particular Reference to Cost and Reliability. The findings of the Electronics-X study which pertain to this report are summarized in Figure 9. A question of interest is to what extent does the Electronics-X findings apply to the case of a programmable processor in tactical weapons? It can be concluded that they do apply, in general, but that there are some very significant differences between the tactical weapon case and the kinds of systems referred to in the report. These differences arise from two factors: the software program length for tactical weapons is rather short, and there are a large number of the weapons produced. From Figure 9 a comparison can be made between the weapon processor and other computer systems with respect to these factors. An avionics system will typically have more than an order of magnitude larger program than the tactical weapon. Because the total software program is small, a large software organization is not required. It is seen that the weapon case is different, and the difference shows up in lower software costs.

If advantage is to be taken of these differences, then software management must be designed to fit the weapon requirements. In some ways, the programmable processor in a tactical weapon is more akin to a small electronic calculator than it is to a computer in a large avionics system. Because of the large

SOFTWARE AND ELECTRONICS-X

CAN IT'S FINDINGS BE EXTRAPOLATED TO MISSILES?

	"SCIENTIFIC"	AVIONICS	MISSILE
PROGRAM LENGTH (ORDERS)	LARGE	10^5	3×10^3
NUMBER OF PROGRAMMERS / NUMBER OF PROCESSORS	10^2	10^{-1}	10^{-3}

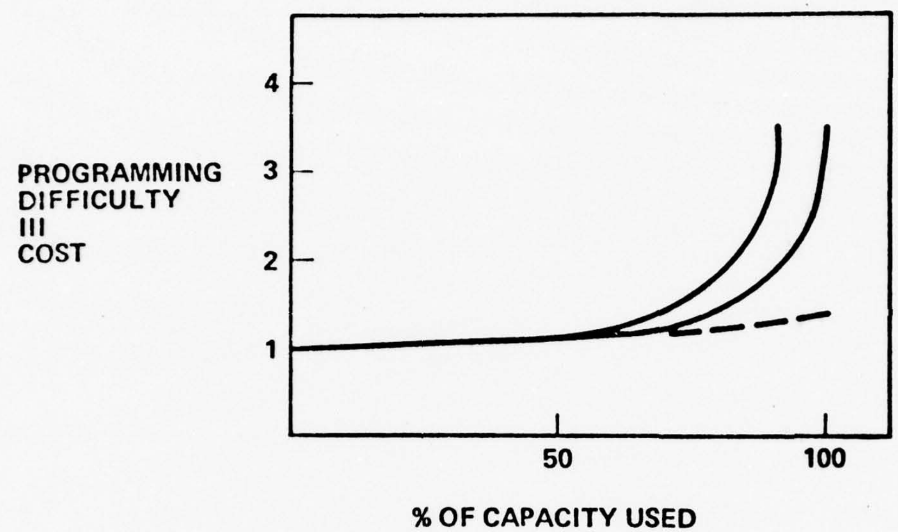
THE MISSILE CASE IS DIFFERENT

Figure 9

number produced, there is a high payoff for optimizing the small program within the constraints of software and hardware modularity. Published data (Figure 10) indicates that the programming difficulty (and cost) increases very rapidly when the system requirements correspond to greater than approximately 70 percent of the processor capacity (2:52). For processing systems in which the programming costs are greater than the hardware costs, this data may provide a useful reference point for processor sizing. Two significant problems occur in the GBU-15 program in applying such sizing criterion. First, the wide disparity of processing requirements may result in an overly capable (and complex) processor to meet the worst case configuration requirements. Conversely, the technology may not be available to support a modular capability increase as required to maintain an optimum usage from the programming viewpoint. Second, the system requirements are somewhat open-ended toward growth capability. Regardless of the initial sizing, growth requirements will eventually use the available processor capacity. Furthermore, in the weapon context, the processor hardware cost will be the major system cost element rather than the programming cost.

Another extremely important aspect of software management is the verification and validation (V&V) techniques that focus on the reliability aspects of tactical weapons software. For better understanding, verification is defined as the determination of whether the results of executing the software product in a <u>test environment</u> agree with specifications. Validation refers to the determination of whether the system in a <u>user's environment</u> causes any operational difficulties. Tactical weapon software differs from other weapon system software in at least five major areas: User interaction, utilization, storage requirements, reliability and maintainability.

SELECT PROCESSOR OF ADEQUATE SIZE



- PARTITION PROCESSING ACCORDING TO COST/TECHNOLOGY CONSTRAINTS

Figure 10

First consider the area of utilization. Unlike conventional computers, the user of a tactical missile processor does not write software to direct the execution of the processor. Instead the processor has predefined software which is initiated via interruptions generated by sensors. The software must operate in real time and is by and large transparent to the user. The implications here are that the user could not rectify a software error even if he knew how to program.

With regard to the utilization of the processors, unlike conventional systems with the order of 10-30 units deployed, tactical weapon processors and their attendant software will be deployed by the tens of thousands. The implications here are clear. The software must be correct before deployment since field changes would be costly and must be kept to a minimum. More time and effort can go into V&V to assure correct software with only a small per unit increase in the software cost since these costs can be analyzed over many copies.

Low storage requirements--8K instructions plus 4K operand --indicate that relatively small programs are written and executed on tactical weapon processors. Small programs are more easily verified and validated than large programs where size can be a measure of complexity. To improve the reliability of the system even further, fault detection and recovery from critical faults will also require some non-volatile operand storage not found in other systems.

Because of the high safety factor involved in tactical weapons, software must have a higher than normal reliability. The software must be correct so that only the aging of the hardware parts form the significant components affecting system reliability. With so many copies in the field, maintainability must be simple, by and large automated through self test and limited

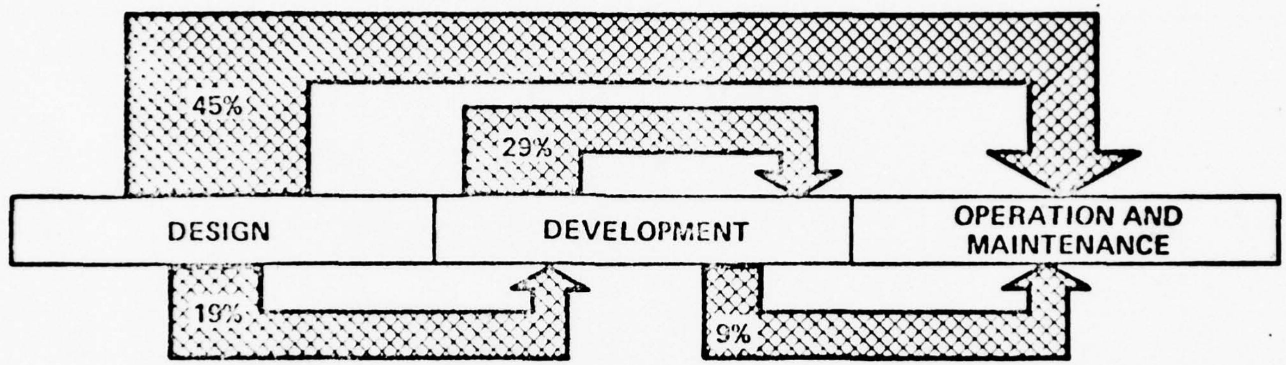
to corrections and updates because changes will be expensive and each unit must again be validated.

Experience (Figure 11) has shown that 54 percent of all reported errors are not discovered until the system is placed in operation. Of these errors, 45 percent originated during the design phase of the software life-cycle. In fact, 64 percent of all reported errors originated during the design phase. Therefore, more emphasis should be placed on software design, including V&V to eliminate software errors prior to deployment.

What can be done to improve the software situation in tactical weapons? To answer this question consider four areas where improvements can be made: management, design, implementation, and evaluation. Software errors can be reduced by making software more visible during its life cycle and by better monitoring and controlling or its progress. Management techniques recommended to achieve this visibility include extending the chief programmer team concept to provide a chief designer team. Because of the small programs in question, in some cases the role of the chief programmer can be expanded into a chief designer team. The improved use of design reviews where material is available prior to its review and technical experts are brought in and consulted early in the software life cycle will also help to reduce errors. Design approaches aimed at reducing software errors include the use of top-down structured (modular) partitioning techniques to minimize the introduction of errors. Review procedures should be included as part of the design approach. Testing procedures and testable designs should be emphasized early in the software cycle. With regard to software implementation, software tools which aid in test generation should also be applied. Evaluation procedures should be distributed throughout the software life cycle with emphasis on early detec-

SOFTWARE ERRORS SHOULD BE DETECTED & RECTIFIED EARLY IN LIFE-CYCLE

EXPERIENCE:



TACTICAL MISSILES:

EARLY EMPHASIS ON V&V IS REQUIRED TO ELIMINATE SOFTWARE ERRORS BEFORE DEPLOYMENT

Figure 11

tion of errors. Various forms of simulation seem best suited to the task of evaluating tactical weapon software. If the designer/implementor does the evaluating, he is apt to introduce the same erroneous implicit assumptions into the test as he introduced into the design. Therefore some form of independent in-house evaluation team should be established, possibly within existing Quality Assurance organizations. Because of the unique features of tactical weapon software discussed earlier, it should be possible to apply these techniques to produce error-free programs.

Software must also be controlled in five major areas. These are software costs and schedules, software responsiveness, software reliability, software evaluation. The V&V techniques previously discussed should be most effective in controlling software. The importance of V&V in controlling these four factors cannot be overemphasized. RAND, TRW, and MITRE show that 50 to 60 percent of the cost of software is spent on testing (2:52). V&V policy, philosophy, and procedures need to be specified early in the software life cycle and applied throughout the life cycle.

The nature of the tactical weapons mission, inability to intervene in case of an error, and the safety aspects of guided weapons dictates that the software must be correct before deployment. To achieve this goal, sufficient visibility, funds, and time must be allocated toward this end. The Armament Development and Test Center (ADTC) at Eglin AFB recognized the importance of supporting current GBU-15 and planned digitally guided weapon systems. By the establishment of the Digital Weapon Software Office within the Computer Sciences Laboratory the management and control of guided weapon software will be effectively accomplished during the development, testing and acquisition mission.

The author has hoped to convey that proper software management is critically important to the digital integration process. In addition, software management techniques that were summarized in this report should provide a baseline for program managers to consider in the development and conduct of their own weapon system projects.

SECTION IV

DEVELOPMENTAL WEAPON SUBSYSTEMS

Increased tactical utility of guided weapons; a greater variety of weapon options to counter a large number of anticipated threats; capability to kill targets in adverse weather; the need to increase reliability and decrease maintenance costs have led to a standardized integration method for a variety of weapon configurations. A logical approach is to provide a flexible digital processor which permits system integration through software changes. This objective has already been attained on a small scale by the demonstration and transition of the digital autopilot into the GBU-15 MGWS. Currently, efforts are under way to broaden the scope of digital integration by developing a digital processor (DP) capable of performing the entire range of computational functions for a guided weapons.

Digital Requirements Analysis

The primary requirement on the DP system is to integrate the subsystems of a modular weapon system. This integration function must be performed for both existing and developmental subsystems. In order for the DP to perform its integration function and other desired weapon functions for future guidance subsystems, growth capability is required both in the processor and in the interface structure. These factors have been used to set the processor requirements and determine a flexible and adaptive hardware structure.

The integration function is involved with the interconnection of the subsystems in a weapon to accomplish the weapon mission. As a first step, the DP must identify which subsystems of the total modular weapon system have been installed in the particular weapon. Then the role of each subsystem in the

overall mission must be determined. As a weapon integrator, the DP must have knowledge (in the software) concerning the interaction of the subsystems and how they must be connected to perform the mission.

Figure 12 shows the three phases of the mission: prelaunch, midcourse guidance, and terminal guidance; and the functions involved in these phases. An initial phase concerned with the weapon assembly process must also be considered in the DP design. During the prelaunch phase, the DP must interface with the aircraft avionics subsystem. The functions which are performed in this phase of the mission are built-in test (BIT) and initialization. The initialization function involves setting the parameters of the weapon subsystem to values appropriate for the mission. After launch the weapon enters a midcourse and then a terminal guidance phase. The flight control function must be performed throughout weapon free-flight. During the midcourse phase, steering signals are derived from midcourse sensors, or possibly by operator interaction if a data link is installed. In the terminal guidance phase, the steering signals are derived from the terminal sensors. The fuzing function is performed at target impact. From this figure, a cursory view of the integration process is obtained in terms of the detailed functions to be performed by the DP.

Figure 13 shows the elements of the weapon system grouped according to their function in the mission. New terms introduced include Long Range Navigation (LORAN), Terrain Contour Matching (TERCOM), and Inertial Measurement Unit (IMU). The DP is required to operate with both existing analog avionics and digital avionics subsystems. Many alternatives are shown for both midcourse and terminal guidance sensors. In some cases the midcourse sensors can also be used for terminal guidance; e.g. Distance Measuring Equip-

THE PHASES OF THE MISSION ARE

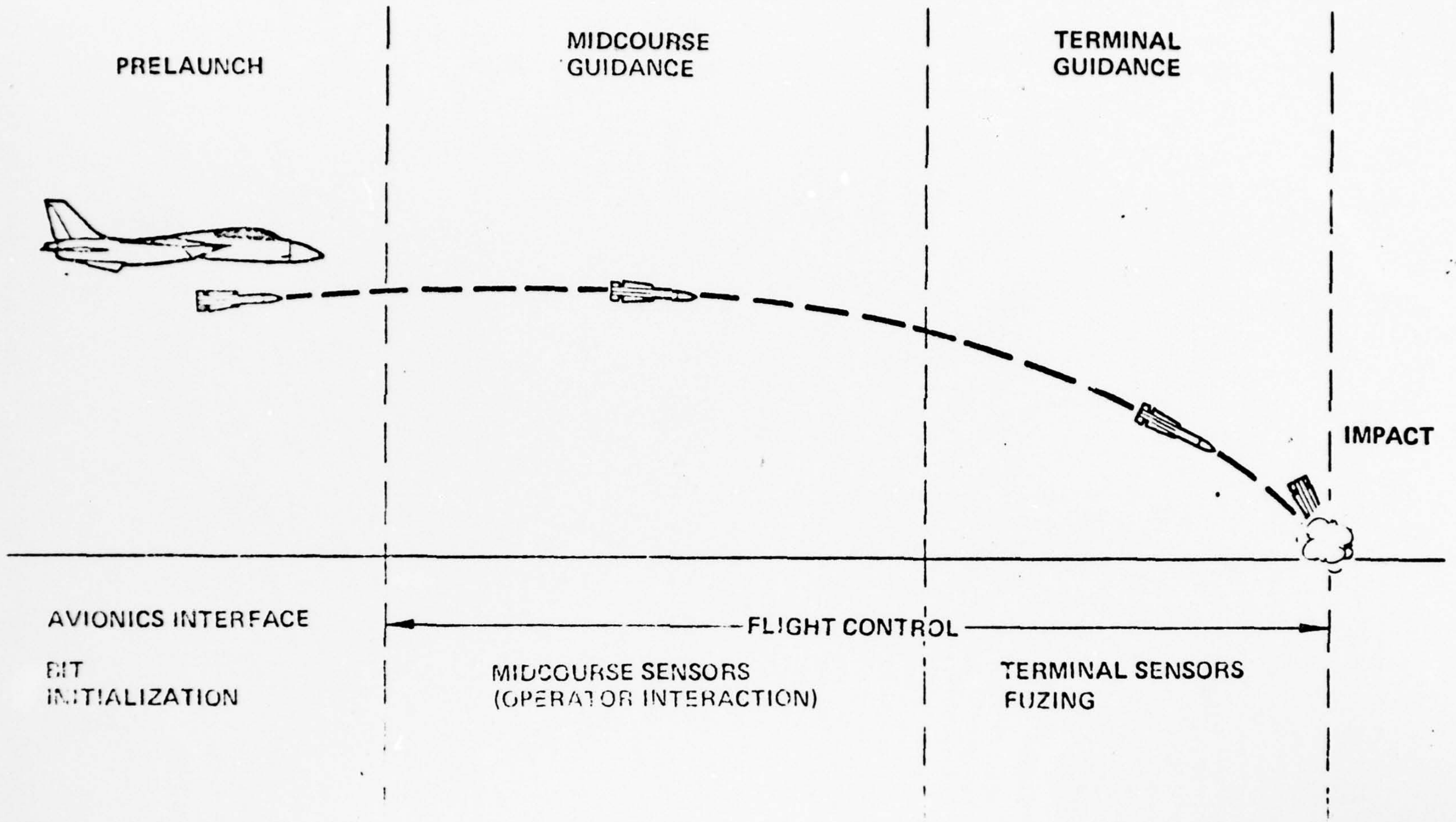


Figure 12

ELEMENTS OF THE WEAPON SYSTEM

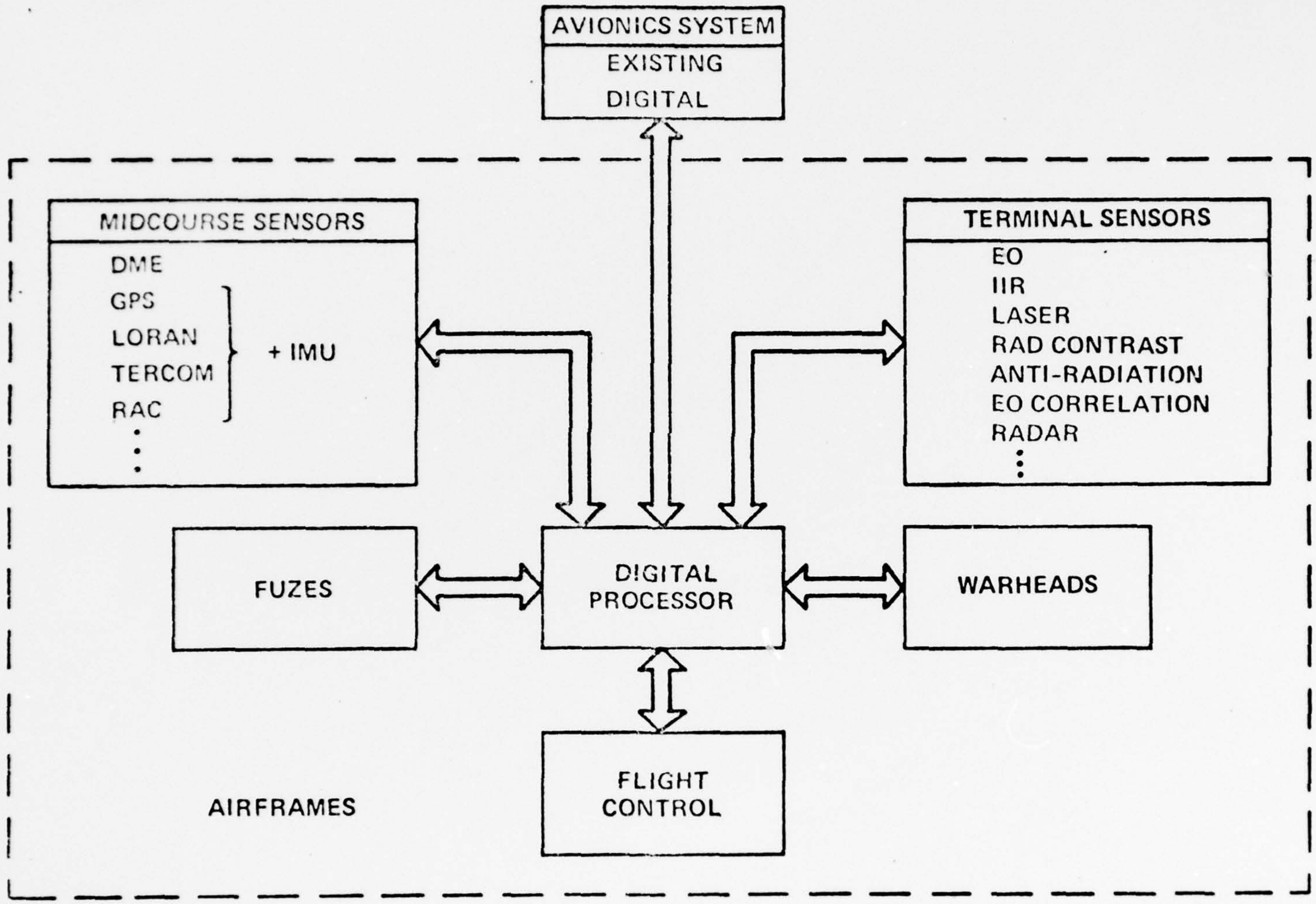


Figure 13

ment (DME) and Radiometric Area Correlation (RAC). Alternative fuzes and warheads are also available for different weapon missions. Alternative forms of flight control are required for different aircraft. The environment in which the DP must perform integration is now defined.

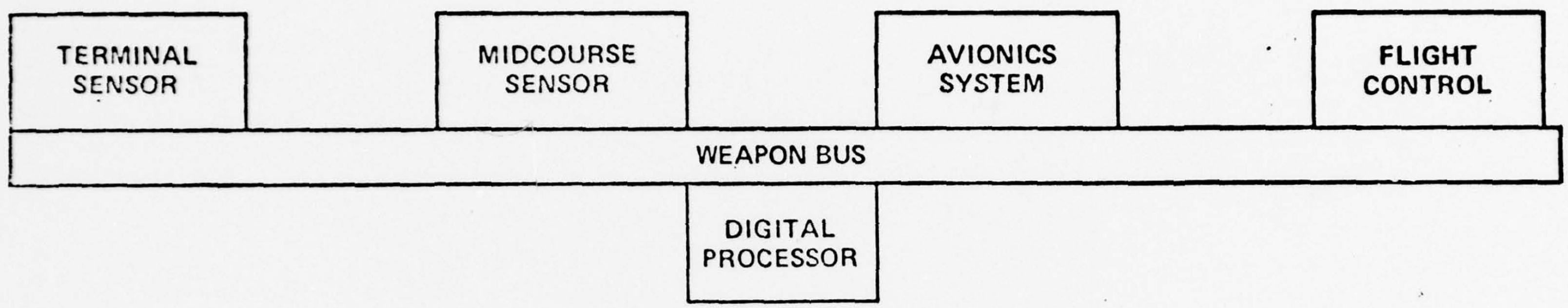
Each subsystem present in the weapon has a unique identifier which is used to extract the particular characteristics of the subsystem. These subsystems are characterized by their data and control input and output requirements and the timing associated with these inputs and outputs. These subsystem characteristics are then input to processing configuration software which determines the required data transfers between the subsystems and the detailed control signals required for the subsystem functions. This determination is made throughout flight as a function of mission phase. Thus, the integration software can be considered to be a simple matching of data requirements with data available.

Figure 14 is a functional block diagram of the selected DP system configuration for weapon integration. The subsystems are connected via a weapon bus which is controlled by the DP. The weapon bus (data and control transfer paths) are incorporated in the weapon bus. This type of interconnection scheme allows the digital system hardware to be independent of the subsystems installed in the weapon. The standard interface of the weapon bus is general purpose in the sense that it provides capability for the most complex subsystem. However, simpler subsystems may utilize only a portion of the interface capability as required.

"Core Function" Concept

The next step in the design process was the development of the "core function" concept in which other functions which are common to many weapon

DP SYSTEM CONFIGURATION FOR WEAPON INTEGRATION



WEAPON BUS UNDER DP SOFTWARE CONTROL

- PROVIDES STANDARD INTERFACE TO ALL SUBSYSTEMS
  - DATA TRANSFERS
  - CONTROL TRANSFERS
- IS INDEPENDENT OF WEAPON CONFIGURATION

Figure 14

configurations were incorporated in the digital processing system. The characteristics of the various subsystems were then used to determine desirable digital system functional interfaces. To aid in this process, three weapon configurations (outlined in Figure 15) were identified for detailed study. The three configurations vary in potential complexity with number 1 being the most complex and number 3 being the least complex. Analysis of these configurations revealed that the Weapons Integration function, Flight Control, and IMU processing were common to most guided weapon systems. The combination of these elements in the DP system forms the "core function" for all developmental guided weapon systems. The development of the hardware and software in the DP system as "module packages" allows the incorporation of advanced technology with minimum impact.

Business Strategy

A most important output of the DP development has been the Weapon Digital System Interface (WDSI) Specification. This Specification provides a complete formal description of the functional and physical characteristics of the DP system hardware and software. The principal value of the WDSI Specification will be to provide a complete set of weapon interface standards, allowing the Air Force to procure all weapon systems to this interface standard. The specification also allows independent procurement of any element of the digital processing system, potentially down to the DP functional element level if desired. Since the DP is the weapon integrator, the Air Force will be able to control the interfaces for all future module procurements. This unique development position should result in the drastic reduction of dedicated hardware and software and a significant savings in the life cycle costs of our tactical guided weapons.

DEFINE REPRESENTATIVE WEAPON CONFIGURATIONS FOR STUDY

	CONFIGURATION		
	1	2	3
AIRFRAME	CRUISE	PWW	CWW
MIDCOURSE GUIDANCE	RAC/IMU	LORAN	DME
TERMINAL GUIDANCE	RAC/IMU	EO	IIR
FUZE	DIGITAL	DIGITAL	DIGITAL

Figure 15

DOD Involvement

The Honorable Malcolm R. Currie (Dr.), Director of Defense Research and Engineering (DDR&E), as banquet speaker at the May 5, 1976 Joint Tactical Missile Conference of the American Preparedness Association made the following comments.

> "Missiles and precision guided weapons will continue to transform the nature of warfare by making the precision application of force at a distance a reality. As we look to the future, no technology will dominate warfare more than that discussed at this conference.
>
> "I am impressed by the tremendous breadth of evolving techniques in propulsion, in new forms of microelectronics and microprocessing, in materials, in sensors, in guidance, in warheads, in multi-spectral imaging seekers. These represent the cream of our advanced technologies in this nation and will be at the heart of the new missile capabilities on which deterrrence and our security will be based.

Dr. Currie's remarks emphasize the importance that DDR&E has placed on the development and application of guided weapon technology. This first became apparent to the author when DDR&E, in 1975, requested a tri-Service plan to consolidate technology base activities in multi-purpose digital processors for tactical guided weapons (12:3). The coordination of the plan was undertaken by the Working Party for Missiles and Rockets and the Joint Technical Coordinating Group for Munitions Development (JTCG/MD). Numerous inter-Service meetings and interchanges resulted in the submission of a coordinated plan through the JTCG Guidance and Control Panel Chairman to the JTCG Chairman. Coordination was received from the Assistant Service Secretaries for R&D prior to acceptance of the plan by DDR&E (17:1-6).

Areas of mutual benefit within the tri-Service plan clearly indicated that digital integration was a desirable feature in the Services tactical guided weapon programs. In addition, digital integration appears to be an area

where Service cooperation in the development stage will lead to common usage of hardware and software technology. Considering the number of guided weapon systems produced, the monetary benefits of digital integration cannot be overemphasized.

SECTION V

CONCLUSIONS

In summary, the purpose of this study was to provide the author with an understanding of the impact of digital integration on the management of tactical guided weapons. Behind this purpose was the premise that system integration through digital processing is the key to cost effective development and deployment of DOD defense systems. Although this study concentrated on guided weapons, the digital integration concept applies to other types of systems such as aerial targets, aircraft avionics, and remotely piloted vehicles (RPV's). For this reason, the process of integrating new subsystems through software change rather than through traditional hardware modification will become increasingly prevalent in DOD systems, and will require adjustments in management strategy.

The introduction of digital technology as the weapon integrator in the GBU-15 MGWS has not been totally accepted by all levels of management within the DOD. Despite a rigorous demonstration of the technical feasibility and cost effectiveness during the validation phase, skepticism remains concerning development goals, cost, tri-Service consideration, and the probability of success in engineering development (20:1-2). These negative feelings have been heightened further through competitor-contractor briefings to DOD officials and the attempt by some to attribute a disproportionate share of guidance and control costs to the autopilot function.

Thorough investigation into the subject areas has revealed that the transition of the digital autopilot into engineering development was recognized, coordinated, scheduled, and initiated in conformance with all of the

documented as well as informal understandings between the Services and with DDR&E. Life cycle cost studies have indicated an appreciable financial advantage in utilizing digital integration. Provisions have been made for digital logistics support and software management within the GBU-15 program to further insure the success of engineering development.

Procurement procedures must be established to insure effective competition as new modules are added to the GBU-15 weapon system. Guidance units such as RAC, GPS, and Low Cost Inertial rely heavily on digital processing. These units are compatible for integration in the GBU-15 family via the digital autopilot or the developmental digital processor. By controlling the interfaces through digital system specifications, the Air Force will prevent a monopoly on modular weapon development and reduce cost through competitive procurement.

Additional benefits will accrue to the Services through continued cooperation in the development of multi-purpose digital processors. This will occur as their usage expands into the areas of aerial targets, aircraft avionics, stores management systems, RPV's, strategic weapons and air-to-air missiles. In each case some or all of the areas discussed in this study will apply. For that reason, digital integration as applied to tactical guided weapons forms a new baseline for managing future efforts within the DOD.

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